SARGEN_IV: Proposal for harmonized European practices for the safety assessment of innovative fast neutrons spectrum reactors considered in Europe

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1.Scope of the project

Technical context

For sustainability purpose, the "**European Sustainable Nuclear Industrial Initiative" (ESNII)** was launched in November 2010 inside the European Union to anticipate the development of a fleet of fast reactors with closed cycle i.e.

- Sodium cooled Fast Reactors (**SFR)**,
- Lead cooled Fast Reactors (**LFR**) and
- Gas cooled Fast Reactors (**GFR)**.
- ESNII also includes some support infrastructures with in particular an irradiation fast spectrum test facility i.e. the FAst Spectrum Transmutation Experimental Facility (FASTEF) able to test both the LFR technology and the Accelerator Driven System (ADS) technology.

1. Scope of the project
The SARGEN_IV consortium

The SARGEN_IV represents an opportunity to prepare the safety assessment for the future innovative reactors. In this respect, it becomes crucial to bring together European designers, TSOs, research organizations and utilities already involved (or to be involved) in innovative reactors and that constitute the best means in order to propose European harmonized safety assessment practices and to consolidate their work within the EURATOM contribution to GIF.

1. Scope of the project

The SARGEN_IV consortium

The SARGEN_IV includes 22 organisations and its complementarity is based on:

- Experts from designers, R&D organizations and universities each having a large knowledge of at least one of the four selected innovative reactors: CEA(Fr), AREVA (Fr), SCK-CEN (Be), AMEC(UK), ANSALDO (It) KIT (De), UJV (Cz), VUJE (Sk), MTA EK (Hu) HZDR(De), RWTH (De)

- Safety experts from all of the European Technical Safety Orrganization (ETSON: IRSN (Fr), GRS (De), VTT (Fi), UJV (Cz), VUJE (Sk) LEI (Li), BELV (Be), PSI (Ch) and from other organizations and universities: UNIMAN (UK), UPM (Sp), ENEA (It)

- One of the most important electricity producer **(EDF)** in Europe which was also largely involved in the French SFR Superphénix operation

- The EU Joint Research Centre in Petten **JRC (Nth).**

2. Objectives and organization

The SARGEN_IV project has four main objectives:

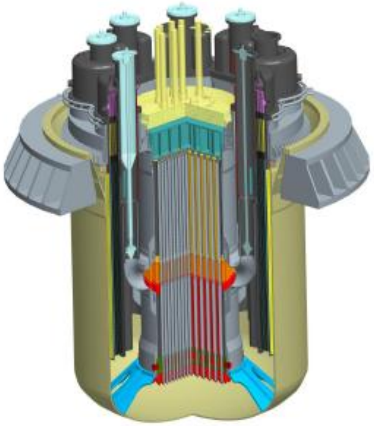
- **Identification and categorization of the critical safety features** associated with the four concepts
- Review of the available safety methodologies followed by **a proposal for harmonization of the safety assessment practices for innovative reactors**
- **Test application** of the proposed European methodology
- **Development of an European roadmap** for the fast reactors safety R&D

SARGEN_IV started in January 2012 with two years duration. Up till now the two first objectives are nearly achieved and their main results are presented hereafter.

3. Identification and categorization of the critical safety features associated with the four concepts

In a first step, relevant safety issues and corresponding initiating events have been identified for the four representative fast reactor systems selected in the ESNII Deployment Strategy.

ALLEGRO – Demonstrator for a gas-cooled GEN-IV reactor system



ALEFRED – Demonstrator for a liquid metal-cooled GEN-IV reactor system

Secondly, to further systematize the consideration of safety issues and characteristics for a consistent build-up of the safety architecture and development of adequate provisions, the SARGEN_IV project aimed at categorizing the individual issues identified for the ESNII concepts to several common "families".

3. Identification and categorization of the critical safety features associated with the four concepts

The categorization was adopted according to:

- **Common phenomena related to:**
  - Materials (fuel, coolant, structure, absorber)
  - Aspects specific to fast reactors
  - Aspects specific to design solutions envisaged for ESNII concepts, and

- **Possible impact on the fulfillment of fundamental safety functions related to:**
  - Control of reactivity
  - Removal of heat
  - Confinement of radioactive materials

3. Identification and categorization of the critical safety features associated with the four concepts

Some examples –

❑ Coolant

- Boiling temperature
  - High for LFRs and FASTEF (ca. 1700°C)
  - Medium for SFRs (ca. 880°C)
  - Not relevant for GFRs (coolant in single, gaseous phase)
- Thermal inertia
  - High for SFRs, LFRs, FASTEF due to the high volumetric heat capacity of coolant and coolant inventories
  - Low for GFRs (provided only by core and structures)
- Reaction with air and water
  - High for SFRs (chemically strongly exothermic)
  - Low for LFRs and FASTEF (no exothermic reactions), but further R&D needed to understand consequences of SG tube ruptures
  - GFRs: Helium inert when in contact with water
- Coolant compatibility with structures
  - SFRs: austenitic steels, such as 316L or 15/15 Ti, not particularly sensitive to corrosion when the sodium is “clean” (i.e: without impurities)
  - LFRs (FASTEF): dedicated corrosion & erosion prevention measures necessary (control of the concentration of dissolved O in the coolant, material coatings)

3. Identification and categorization of the critical safety features associated with the four concepts

Some examples

❑ Aspects specific to fast reactors

- Coolant reactivity void coefficient
  - Could be highly positive for SFRs, based on the earlier core designs (efforts ongoing to reduce the coefficient for ASTRID)
  - Still positive, but lower for LFRs (ALFRED, 2$)
  - Low for GFR (ALLEGRO, 0.25$)
  - Negative for FASTEF (-7.7$)
- Considered need of mitigation measures (core catcher) in case of core melting
  - Yes for SFR
  - No for ALFRED LFR and FASTEF
  - Not determined for GFR
- Sensitivity to coolant blockage accident related to the power density
- Risk of positive reactivity insertion due the core compaction in particular as a consequence of earthquake loadings

4. Review of safety assessment methodologies

Various safety methodologies are already (or will be) available that could be applied to the ESNII prototypes, pilot plants and demonstrators, which have been disseminated and analyzed inside the SARGEN_IV consortium such as:

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- Methodologies dedicated to innovative reactors and issued by the **GIF Reactor Safety Working Group (RSWG)** and from the **International Project on Innovative Nuclear Reactors and Fuel Cycles (IAEA/INPRO)** safety assessment methodology

- **National safety approaches** (France, Germany, Spain, Finland, Belgium) and the associated experience feedback in particular for the SFRs built in France and Germany as well as for the Finish European Pressurized Reactor (EPR^{TM})

4. Review of safety assessment methodologies

- Safety approaches adopted in **European collaborative projects** related to the four concepts (CP-ESFR for SFR, LEADER for LFRs, GoFastR for GFR and CDT for FASTEF)

- Documents coming from international organizations such as I**AE**A or the **Western Europe Nuclear Regulators' Association (WENRA)** and available for the safety assessment of innovative reactors including methodology used for the European NPP "stress tests"

Four documents have been issued related to this review and have been used to prepare the proposal for a harmonization of the safety practices for innovative reactors.

5. Proposal for a harmonization of the safety practices for innovative reactors

Some key points :

- **Safety assessment should be performed for both reactor and fuel storage**, in all plant states and conditions – including maintenance stages - over the lifetime of the installation, up to decommissioning.

- Waste management and workers radiological protection should also be taken into account

- Moreover, human and organizational factors with also man-induced situations are a part of the safety assessment

- **Security/safeguard aspects should be dealt in an integrated manner.**

5. Proposal for a harmonization of the safety practices for innovative reactors

Some key points :

- Besides, **chemical effects could be a challenging issue** with regard to designs of GEN-IV reactors currently in consideration***.***
- **Ambitious safety objectives are targeted** even though safety goals of GIF are not particularly prescriptive when specifying objectives for GEN-IV nuclear power plants (NPP).
- Nevertheless, **the goal is to reduce potential consequences and impact on public, workers and environment** as well as occurrence/frequency of failures, incidental and accidental situations.

5. Proposal for a harmonization of the safety practices for innovative reactors

The work highlights the importance of safety principles in achievement of safety objectives:

- Defense-In-Depth (DiD) principle remains fundamental. An overall reinforcement of DiD is expected for GEN-IV NPP, including improved independence between all levels of DiD. A particularly important issue for GEN-IV reactor could be to clearly define level 4 for each plant design.
- Other principles as barriers, As Low As Reasonable Achievable (ALARA) principle and As Low As Reasonable Practicable (ALARP) principle should also be enhanced.
- Concerning fundamental safety functions, an inherent approach should reinforce the fulfillment of fundamental safety functions e.g. the consequences for some situations should be reduced and the grace periods should be extended. For the same reason, the use of passive systems can be envisaged.
- Practical elimination is another important principle, but it requires in-depth analyses for GEN-IV NPP. Lastly, the need of two complementary and integrated approaches, the deterministic and the probabilistic ones, is reiterated.

5. Proposal for a harmonization of the safety practices for innovative reactors

About the safety assessment:

- A safety assessment should be performed with regard to safety objectives in particular those proposed by WENRA and considering safety principles, SARGEN_IV project proposes to use some methodologies such as the Qualitative Safety Features Review (QSR), the Objective Provision Tree (OPT) and the Phenomena Identification and Ranking Table (PIRT) for the global safety assessment process to provide feedback.

- Concerning the detailed safety assessment, there is no clear specificity for GEN-IV NPP. Nevertheless, the comprehensive set of postulated initiating events could be quite different from GEN-III NPP. Moreover, they should be assessed with more stringent rules and acceptance criteria.

5. Proposal for a harmonization of the safety practices for innovative reactors

About the safety assessment:

- Assessment of hazards would be a challenging aspect of next generation of NPP safety assessment and should be improved, which is confirmed by the first insights of Fukushima Daiichi TEPCO reactors accidents. These first insights, on the basis of the European Nuclear Safety Regulators Group (ENSREG) specifications and conclusions, should be extrapolated to new designs, which poses another challenge for GEN-IV NPP.

- For example the total loss of power sources, the total loss of the ultimate heat sink(s) and the combination of both have to be considered with also the management of a severe accident in this case. Provisions to cope with these events notably to improve the grace period before cliff-edge effects and thus allowing back-up measures to be implemented have to be defined and should be considered as hardened equipments.

6. Further work

The next phase of the SARGEN_IV project comprised the **test application of the proposed harmonized European practices** to the selected initiating events of the reactor prototypes.

This will be aimed to identify **needs on R&D and provide feedback to the harmonized European practices** in support for the EURATOM contribution to the preparation of GEN-IV “white paper” on nuclear safety for European concepts.

THANK YOU FOR YOUR ATTENTION!

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